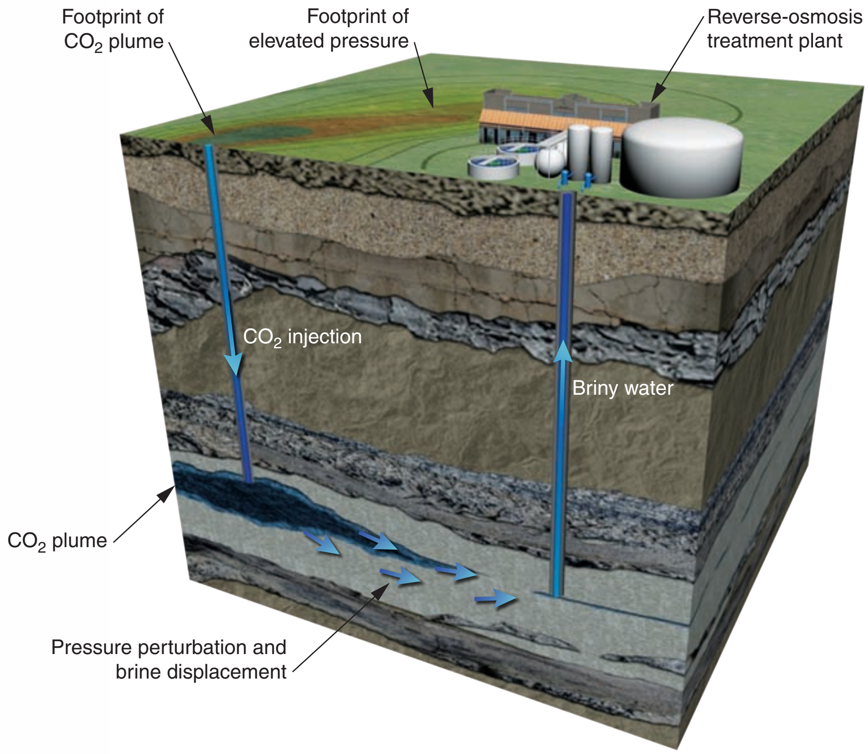
Carbon Dioxide into the Briny Deep

WITH every passing year, the amount of carbon dioxide (CO_2) in the atmosphere increases. Because of the way this gas absorbs and emits infrared radiation, excessive quantities can cause the warming of Earth's atmosphere. Natural sources of atmospheric CO_2 such as volcanic outgassing, the combustion of organic matter, and the respiration processes of living aerobic organisms are nearly balanced by physical and biological processes that remove the gas from the atmosphere. For example, some CO_2 dissolves in seawater, and plants remove some by photosynthesis.

However, problems arise with the increased amounts of CO_2 from human activities, such as burning fossil fuels for heating, power generation, and transport as well as some industrial processes. Natural processes are too slow to remove these anthropogenic amounts from the atmosphere. In 2008, 8.67 gigatons of carbon (31.8 gigatons of CO_2) were released worldwide from burning fossil fuels, compared with 6.14 gigatons in 1990.

The present level of atmospheric CO_2 is higher than at any time during the last 800,000 years and likely is higher than it has been in the last 20 million years. Researchers around the world are exploring ways to dispose of this excess. One proposed approach, called carbon capture and sequestration, is to store CO_2 by injecting it deep into the ocean or into rock formations far underground. The G8, an informal group of economic powers including the U.S., has endorsed efforts to demonstrate carbon capture and sequestration. The international forum recommended that work begin on at least 20 industrial-scale CO_2 sequestration projects, with the goal of broadly deploying the technology by 2020.

Several carbon sequestration projects are already under way. One, under the North Sea, is part of an oil drilling operation that separates CO_2 from natural gas and traps it in undersea rock formations. Other projects are using sequestered CO_2 to push oil around underground so that drillers can maximize the quantity of crude oil they remove—a process called enhanced oil recovery.



In active reservoir management, as carbon dioxide (CO_2) is pumped into underground sandstone formations, briny waters are pushed to the surface and treated by reverse osmosis to create freshwater. The recirculating process inherent in active CO_2 reservoir management will naturally generate the pressures needed for reverse osmosis, considerably lowering the cost of desalination. (Rendering by Sabrina Fletcher.)

An alternative approach, being pursued by researchers at Lawrence Livermore and the Department of Energy's National Energy Technology Laboratory, involves putting CO_2 back into the ground while simultaneously producing freshwater. According to Livermore geochemist Roger Aines, who leads the Laboratory's work on this project, vast underground sandstone formations are filled with very salty water, many times saltier than the ocean. The idea is to pump CO_2 into these rock formations, thereby pushing briny water up into a reverse-osmosis water-treatment plant where most of the salt can be removed. The result is to increase volume for storing CO_2 in the underground formation while producing freshwater aboveground.

Although this water might be too salty to drink, it would provide a critical resource for industrial processes that require huge quantities of freshwater. Petroleum refining, for example, consumes 1 to 2 billion gallons of water per day. Even technologies designed to reduce greenhouse gases, such as the biofuels production process, are increasing demands on the world's water resources.

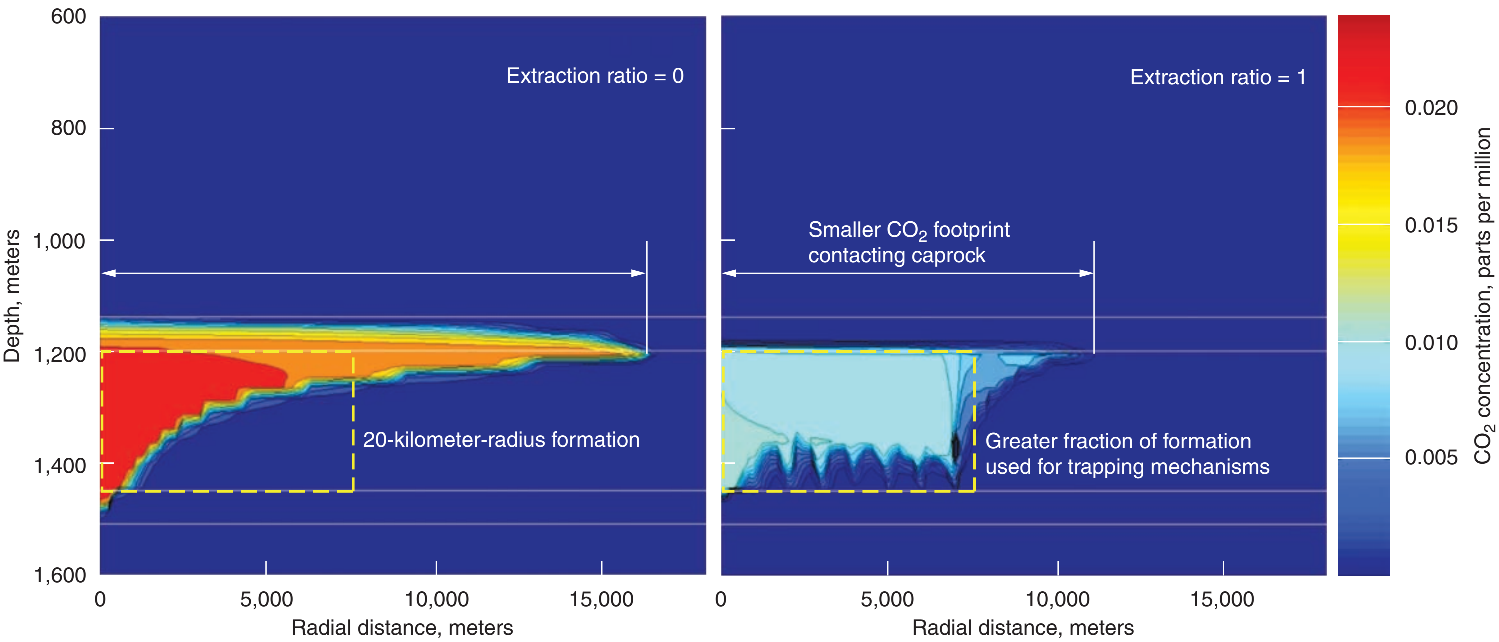
Affordable Freshwater

"Reverse osmosis is typically quite expensive because pressures of over 1,000 pounds per square inch [or nearly 7 megapascals] must be generated to push the salty water through the filters," says Aines. For the Livermore project, however, pumping CO_2 underground would naturally create the pressures needed to force water to the surface and into reverse-osmosis filters, vastly reducing desalination costs.

After treatment by reverse osmosis, a much more concentrated salty brine remains and must be disposed of. Also, when stored underground, the sequestered CO_2 is in a supercritical state, where it is neither a liquid or a gas. But because its properties will be similar to those of a liquid, it will have the potential to move around and disturb other rock formations. According to Aines, the Livermore approach is designed to address both issues. Current plans are to reinject the supersalty brine and use it in the space created by extracting water to keep the injected CO_2 in place. This balancing act is called "active reservoir management." Because the ability to remove water allows engineers to manage the pressure in the storage zone, active reservoir management can be an important way to ensure that CO_2 is stored safely and fills the reservoirs to capacity. "By changing pressures," says Aines, "we should be able to move reinjected brine and CO_2 around to fill the entire reservoir."

Active reservoir management not only produces freshwater and reduces pressure buildup underground, but it also reduces the ultimate footprint of the underground CO_2 reservoir. Simulations indicate that the radius of an unmanaged underground reservoir is about twice that of an actively managed one.

"We have worked through the economics of active reservoir management with industrial partner PerLorica," says Aines, "and the results look good." A small, private firm in Rough and Ready,



Computer simulations indicate that an actively managed CO_2 reservoir will occupy a much smaller underground footprint (right) than a reservoir that is passively managed (left) because more of the formation can be used to trap the CO_2.

California, PerLorica, Inc., provides water-treatment monitoring and consulting services to customers in the U.S. The company specializes in process control and monitoring using a range of proprietary software and related process management services.

"However, there are several caveats to making this technique work effectively," notes Aines. For one thing, the chemistry is complicated. The reverse-osmosis process will work on brine formations with saline levels up to about 85,000 parts per million (ppm). While ocean salinity is typically about 35,000 ppm, the water salinity in some sandstone formations can be as high as 300,000 ppm. Fortunately, about half of the formations have brine with salt content below the 85,000-ppm range.

CO_2 on the Move

A Laboratory team is using the fluid dynamics code NUFT-C (for Nonisothermal, Unsaturated Flow and Transport with Chemistry) to address some of the other caveats. The original NUFT code was designed almost 20 years ago to simulate the movement of multiple liquids and gas in saturated or unsaturated porous media. The code has been modified over the years to meet the needs of larger projects and to capitalize on the ever-expanding capabilities of large computers. "This project definitely presents a high-performance computing challenge," says Aines.

Researchers have applied NUFT-C in the past, for example, to examine the flow of subsurface pollutants and the behavior of oil and surrounding fluids and rock in individual oil wells. Active reservoir management presents a more complicated scenario. A storage reservoir may be tens of kilometers across and have separate wells for extracting briny water and injecting CO_2 and processed brine into the underground formation. NUFT-C simulations are beginning to reveal how CO_2, the less buoyant briny water, and the denser reinjected brine move through and around rock formations.

The project team is running the initial reservoir simulations on the massively parallel computers at the Laboratory's main site. In the future, simulations may be performed in a supercomputing facility at the proposed Livermore Valley Open Campus. Access requirements for the Open Campus would be more streamlined than those in place now for national security laboratories, thereby facilitating collaboration with partners from government entities, universities, and private companies working with researchers at Lawrence Livermore or Sandia national laboratories.

Aines notes that a National Applied Energy Simulation Center has been proposed for the Open Campus. He adds, "Our project may well be an early user of the center's supercomputers."

—Katie Walter

Key Words: active carbon dioxide (CO_2) reservoir management, carbon capture and sequestration, NUFT-C code.

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